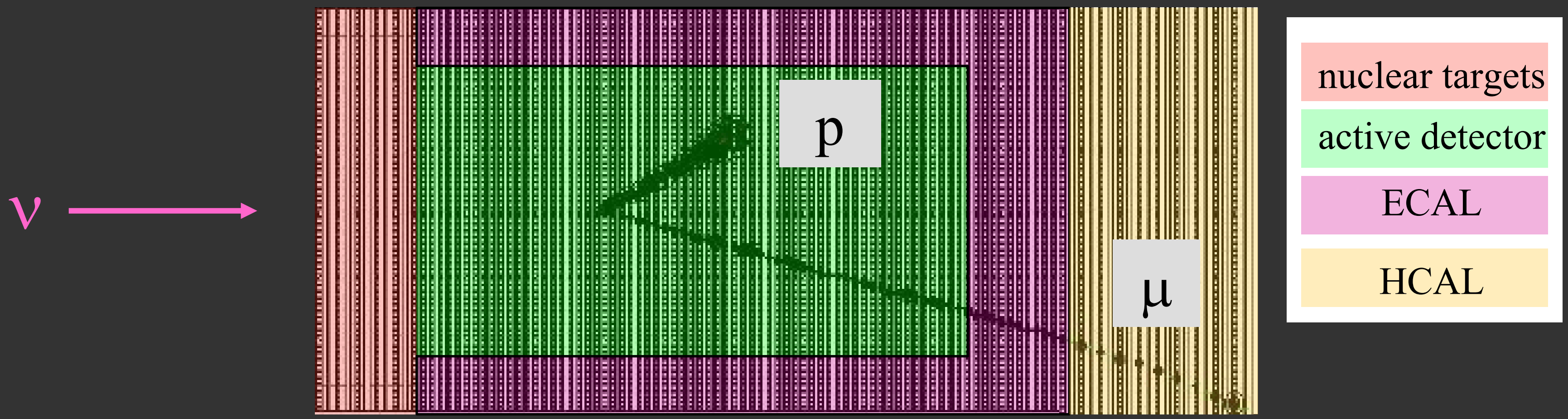
The MINERνA Experiment



S. Manly
University of Rochester
Department of Physics and Astronomy

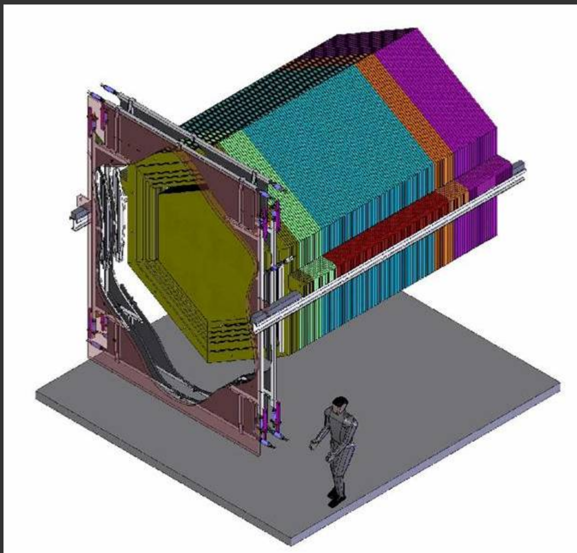
NUFACT ’06, Aug. 2006
Irvine, California

What is MINERνA?

MINERνA proposes to build a low-risk ν detector with simple, well-understood technology …

(MINOS ND)

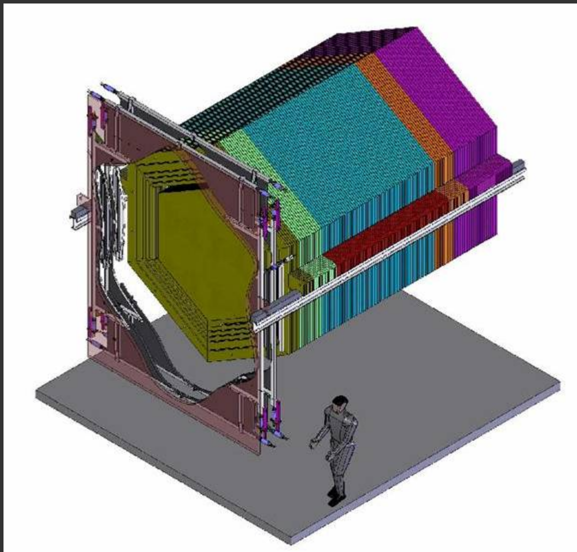
MINERνA



… in the NuMI beam just upstream of MINOS.

What is MINERνA?

MINERνA proposes to build a low-risk ν detector with simple, well-understood technology …



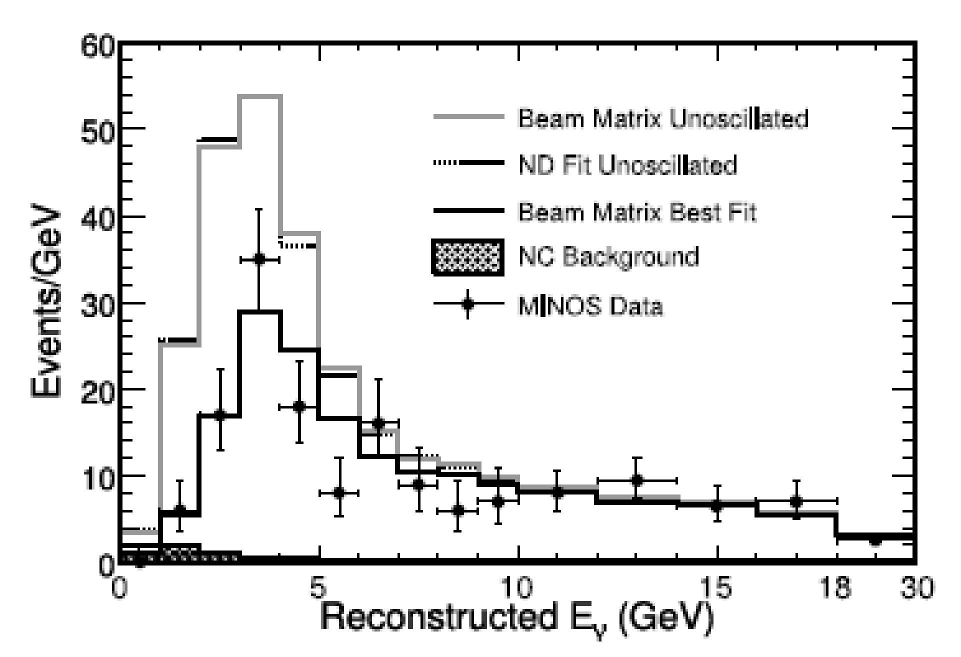
- Active core is segmented solid scintillator
  - tracking (incl. low momentum protons)
  - particle identification
  - few ns timing (track direction, identify stopped K±
- Surrounded by electromagnetic and then hadronic calorimeters
  - Photon (π^o) and hadron ($\pi^{\pm}$) energy measurement
- C, Fe and Pb nuclear targets upstream of solid scintillator core
- MINOS near detector as high energy μ spectrometer

Motivation for MINERνA

Entering a period of precision neutrino oscillation measurements …

- Precision understanding of low energy (Few GeV) neutrino cross sections
- Models
- Nuclear effects
- Final state details

Recent results from MINOS



hep-ex/0607088

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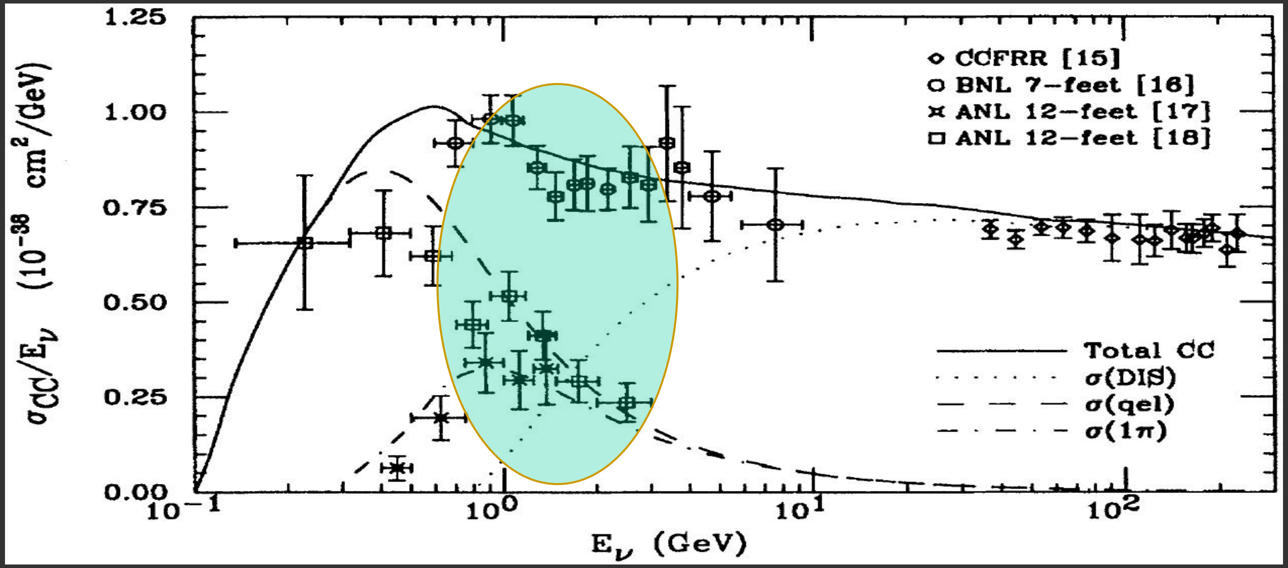
*Lipari, Lusignoli and Sartogo, PRL **74**, 4384 (1995)*



Motivation for MINERνA

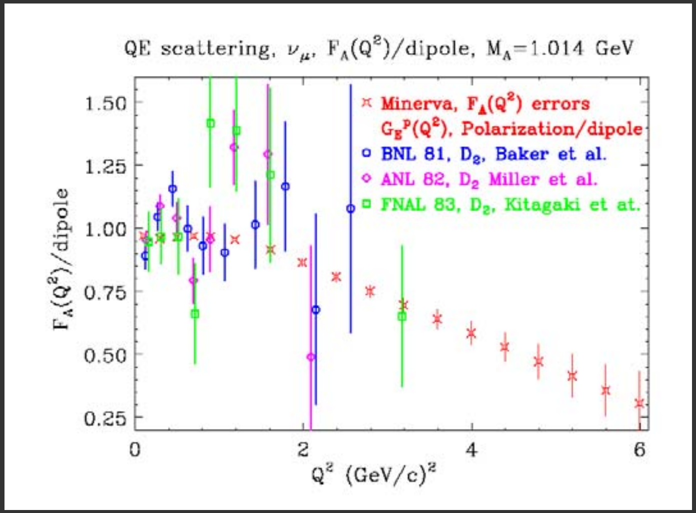
The recent ***APS Multidivisional Neutrino Study Report*** predicated its recommendations on a set of assumptions about current and future programs including:
support for current experiments, international cooperation, underground facilities, R&D on detectors and accelerators, and

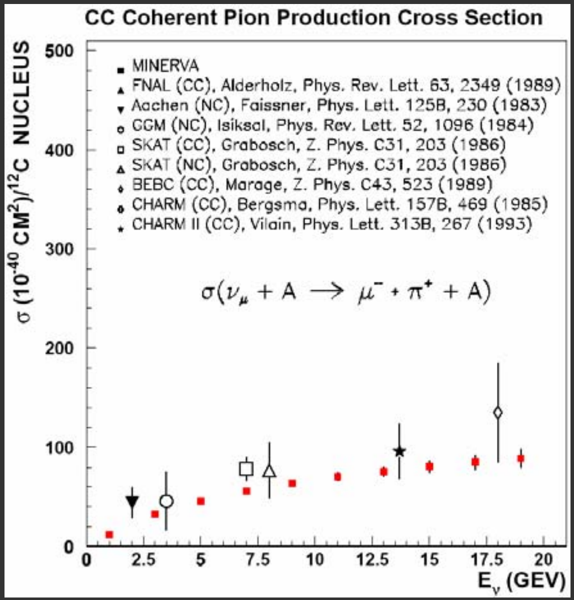
"determination of the neutrino reaction and production cross sections required for a precise understanding of neutrino-oscillation physics and the neutrino astronomy of astrophysical and cosmological sources. Our broad and exacting program of neutrino physics is built upon precise knowledge of how neutrinos interact with matter."

Motivation for MINERνA

Cross sections interesting in their own right …

- Determination of axial form factor
- Duality in neutrino interactions
- Nuclear effects
- Coherent pion production





MINERνA Collaboration

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The College of William and Mary

** Co-Spokespersons*
 # Members of Executive Committee

HEP/NP Partnership

- This partnership is truly a two-way street
  - significant NP participation in MINERvA because of overlap of physics with Jefferson Lab community

Neutrino Physics Comes to JLab

The inner workings of the sun, the mysteries of dark matter and dark energy and the structure of the early universe all may be unlocked by one cosmic key: neutrinos. Now, new research carried out in Jefferson Lab's experimental Hall C may help provide insight into neutrinos, the force that governs their behavior and, surprisingly, the structure of the nucleus of the atom.

Fermilab Today

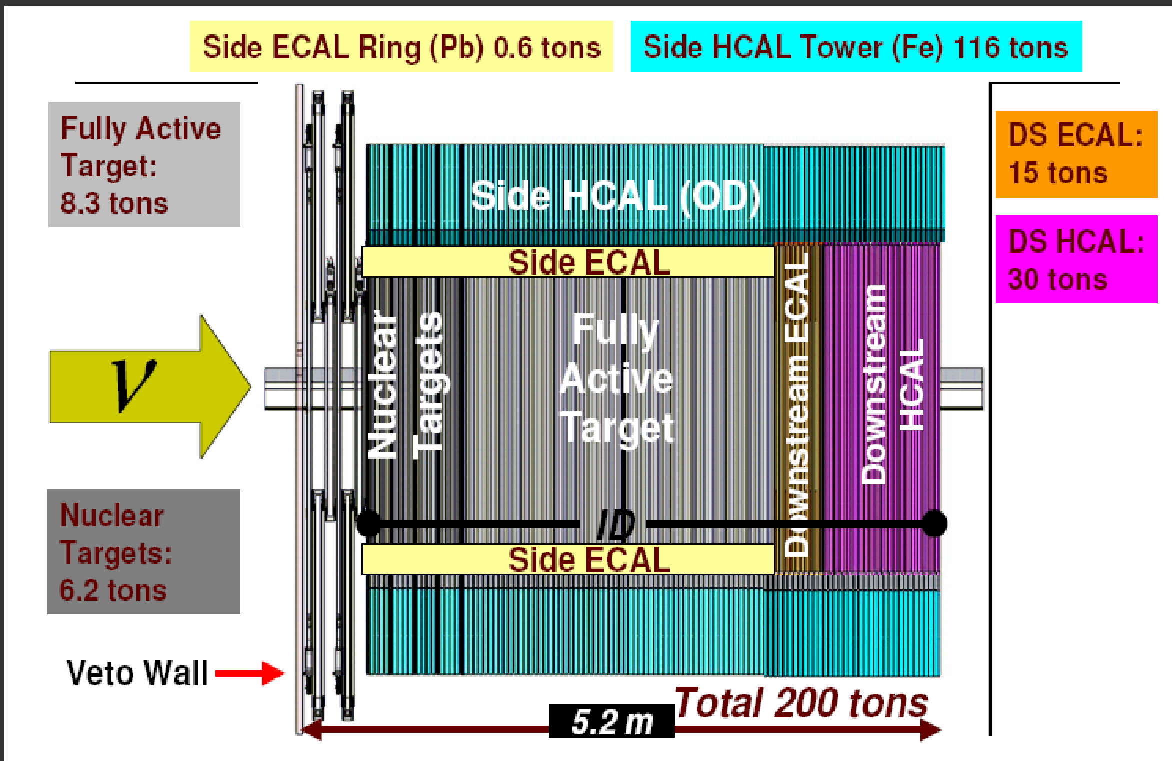
Nuclear Option: MINERvA Attracts Nuclear Physicists

This is the fourth article in a series on the MINERvA neutrino experiment.

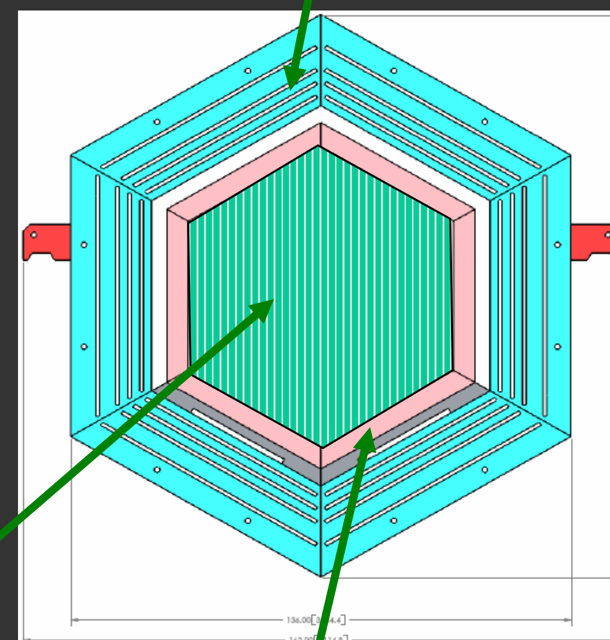
"MINERvA offers us the possibility of making a bridge in our understanding between the longer distance-scale properties of the nuclear force--responsible for the properties of nuclei--and the very short-distance scales explored in particle physics," says Ransome. "And this intermediate distance scale is of great interest to both communities."

- JLab program (JUPITER)
  - data for neutrino cross-section modeling
  - already run one dedicated experiment
  - Active program of data mining with neutrinos in mind

MINERνA Detector



Side View



Front View

Outer Detector (OD) Layers of iron/scintillator for hadron calorimetry:

6 Towers

Inner Detector Hexagon – X, U, V planes for stereo view

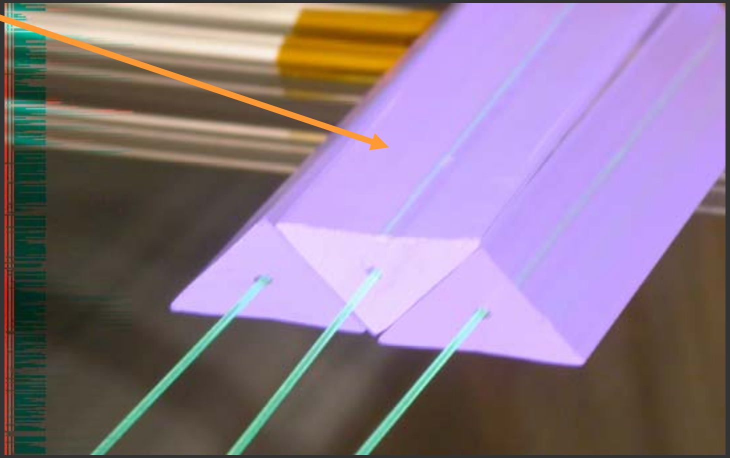
Lead sheets for EM calorimetry

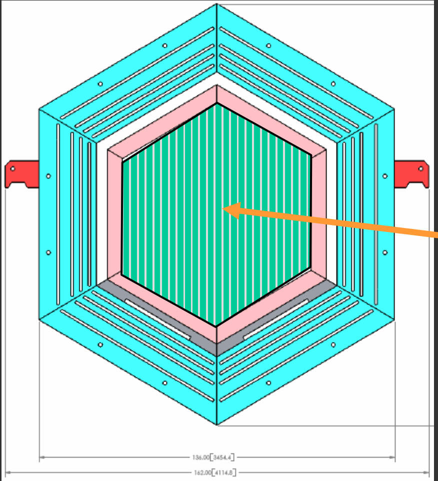
MINERνA Detector

Detector Channel Count:

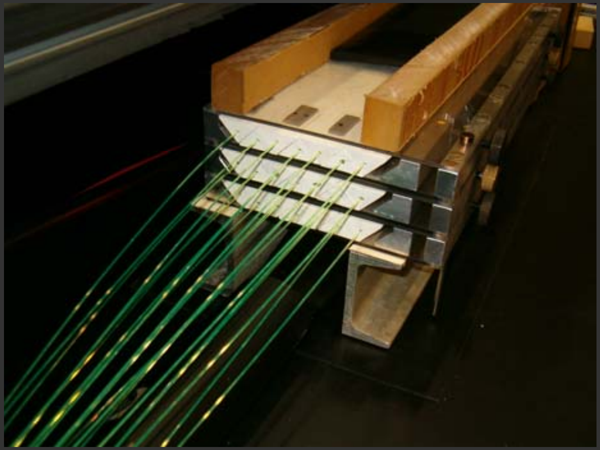
- ❖**31,000 channels**
  - •80% in inner hexagon
  - •20% in Outer detector
- ❖**503 M-64 PMTs** (64 channels)
- ❖**128 pieces of scintillator per Inner Detector plane**

Active elements are 1.7x3.3 cm triangular bars of extruded scintillator with embedded 1.2 mm WLS fibers





Inner detector is totally active scintillator strip detector. Alternating planes rotated by 60 degrees to make 3 views (XUXV)



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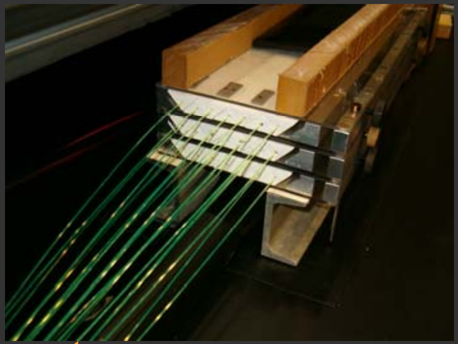
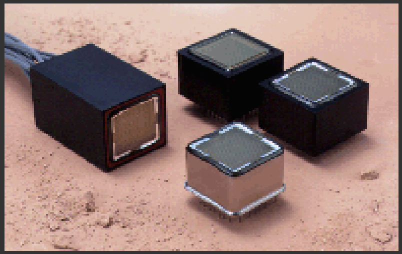




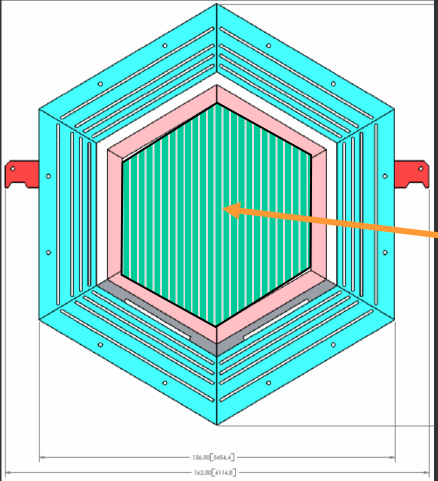
Readout by Hamamatsu M64

+

FE Readout Based on TriP-t ASIC and LVDS chain

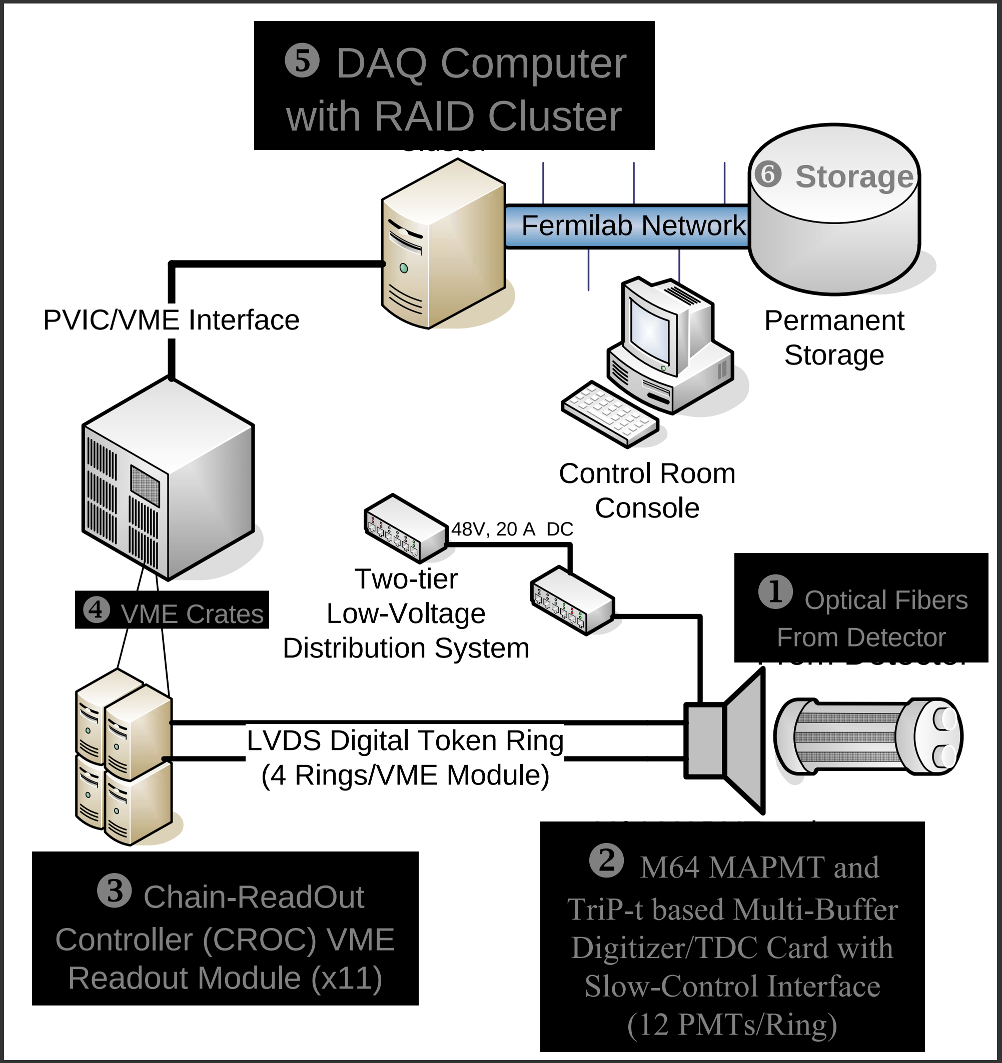
ADC (triple range) plus few ns resolution timing

Inner detector is totally active scintillator strip detector. Alternating planes rotated by 60 degrees to make 3 views (XUXV)



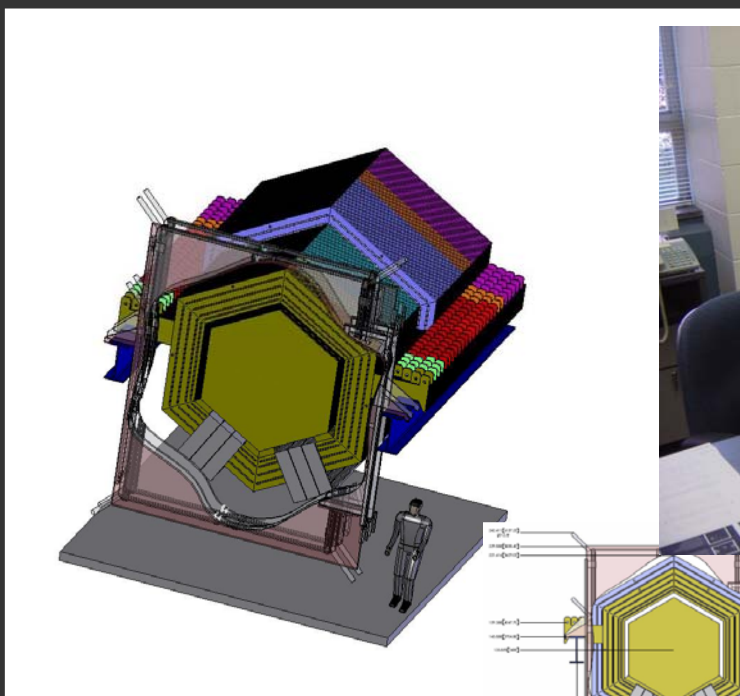
Electronics

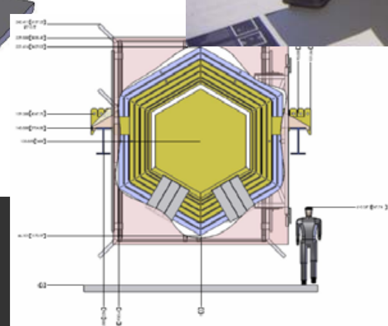
- Front-end Electronics
  - One board per PMT
  - Digitization via TriP-t Chips, taking advantage of DØ design work



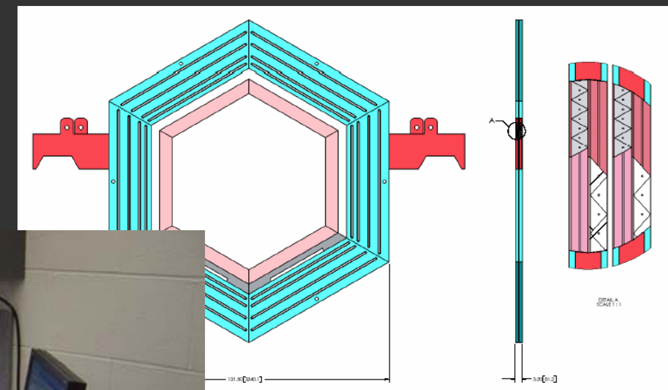
MINERνA: R&D / Prototyping / expected performance

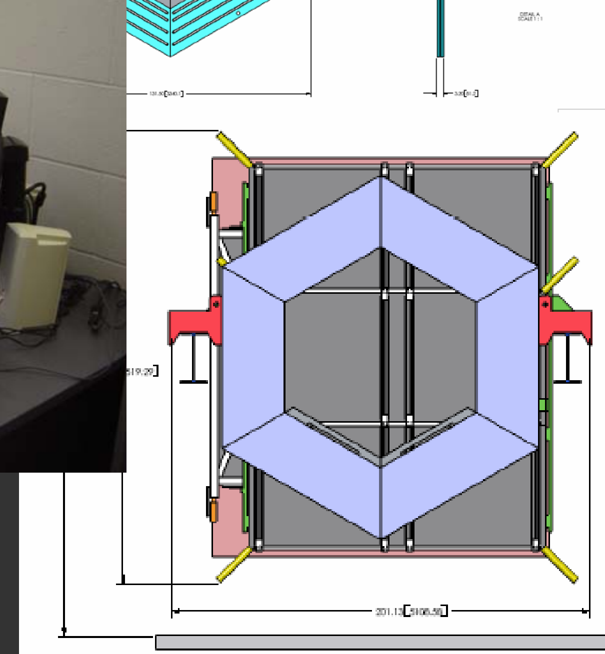
Detailed design, now down to fine-tuning





Robert Flight

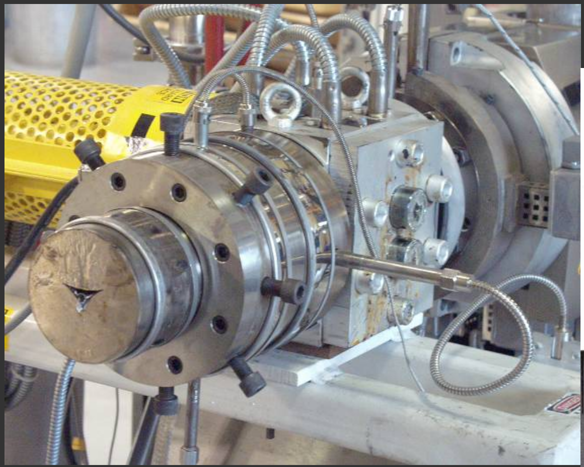




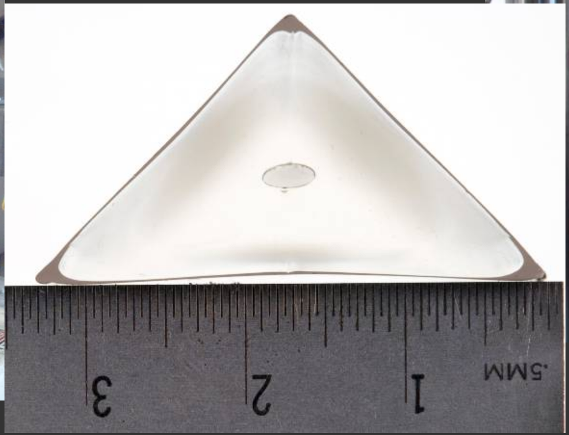
MINERνA: R&D / Prototyping / expected performance

- Inner detector scintillator triangles
  - Demonstrated feasibility of meeting mechanical specs
  - Provide scintillator for light yield measurements

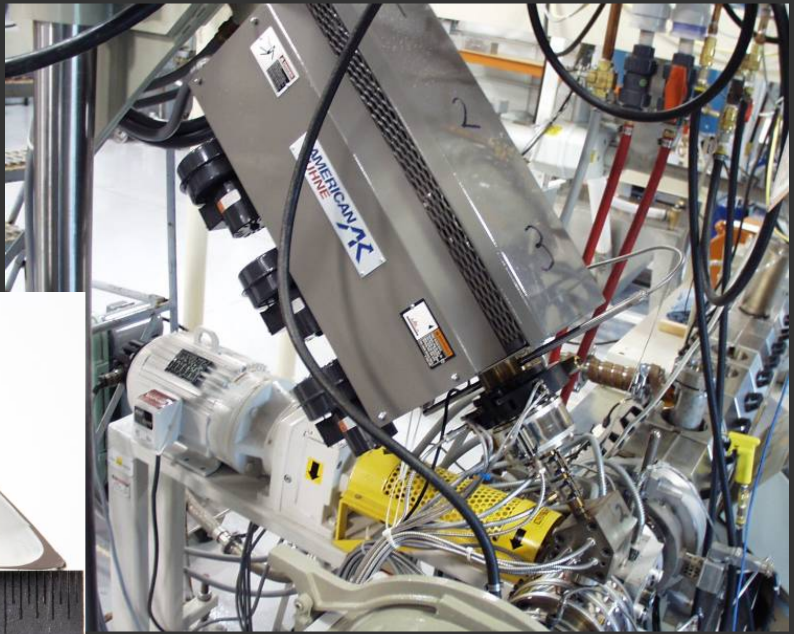
Triangle Die



X-section of scintillator

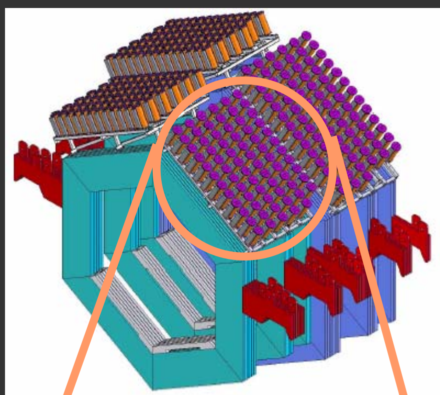


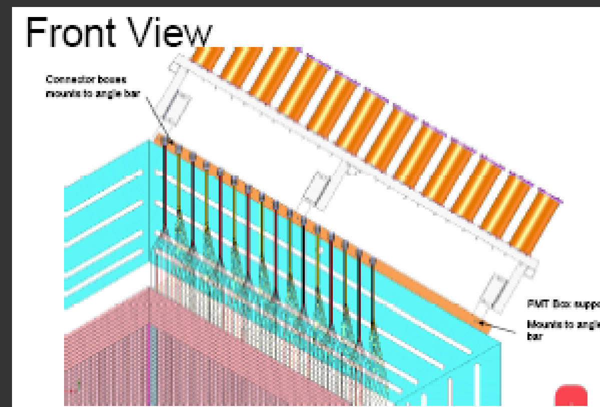
Co-Extruder



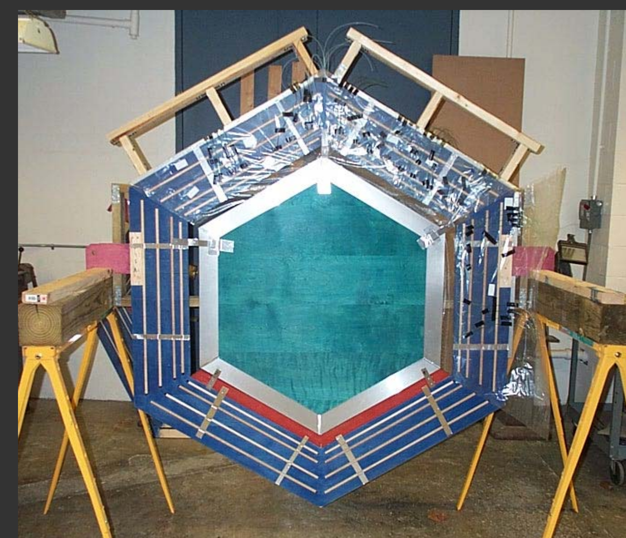
MINERvA: R&D / Prototyping / expected performance

Fiber routing and mechanical prototypes of layers





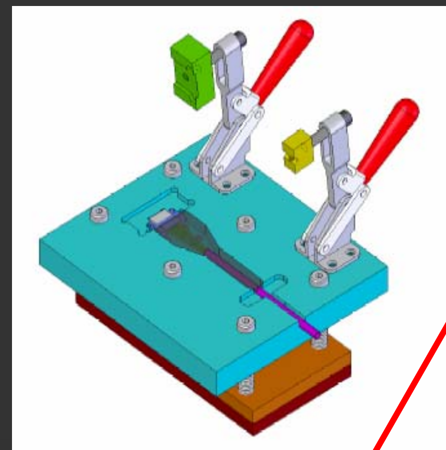
prototype module (layer substructure)

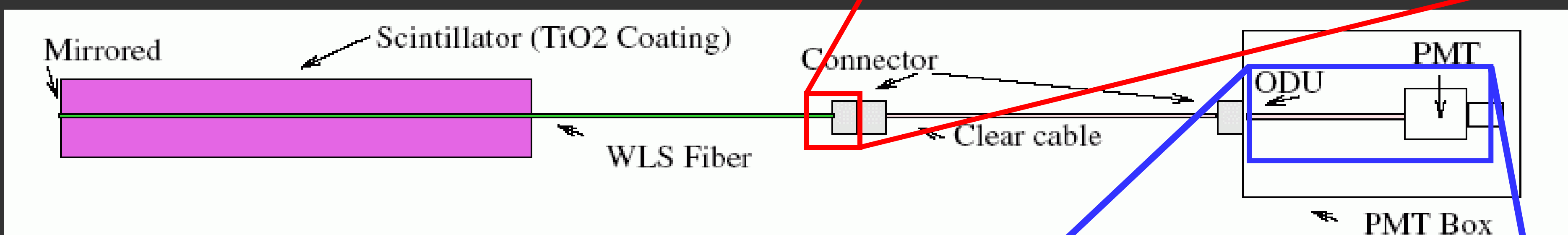


prototype PMT rack

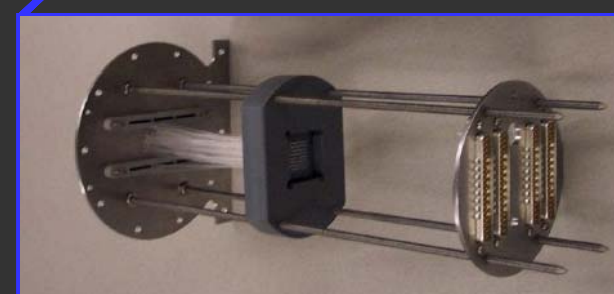
Bob Bradford
Jaewon Park
Zack Desantis

MINERνA: R&D / Prototyping / expected performance

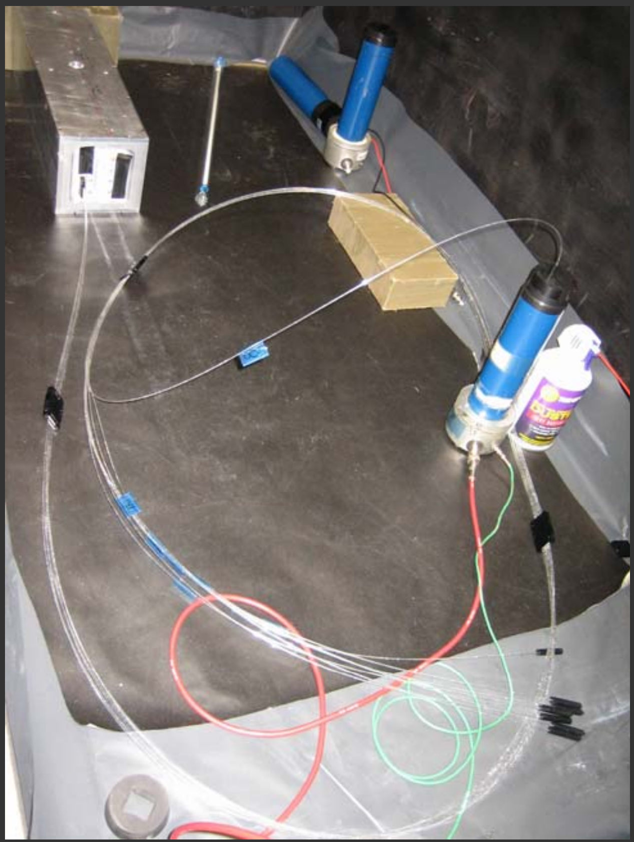




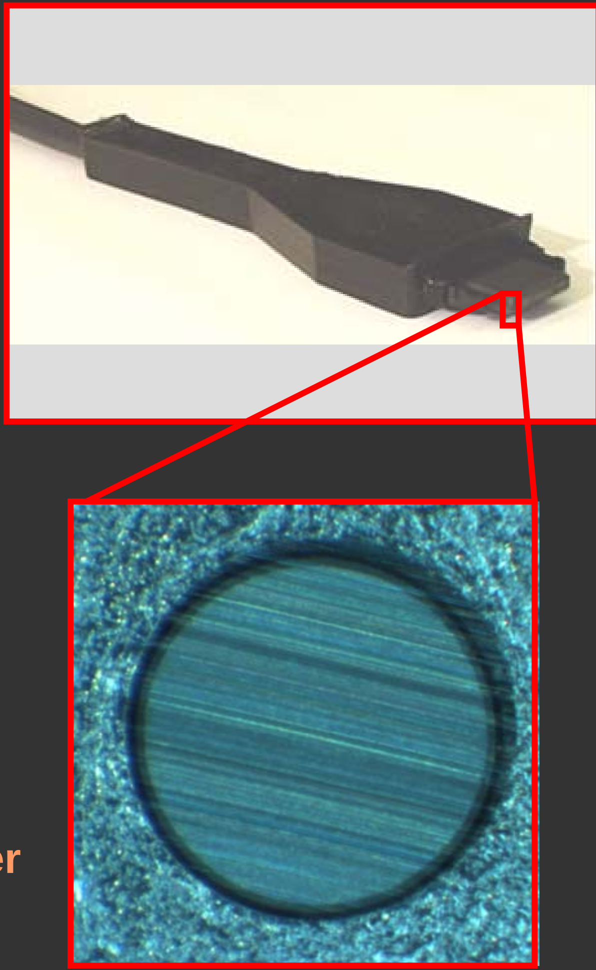
Optical path:
fibers/cables/connectors/PMT



MINERνA: R&D / Prototyping / expected performance

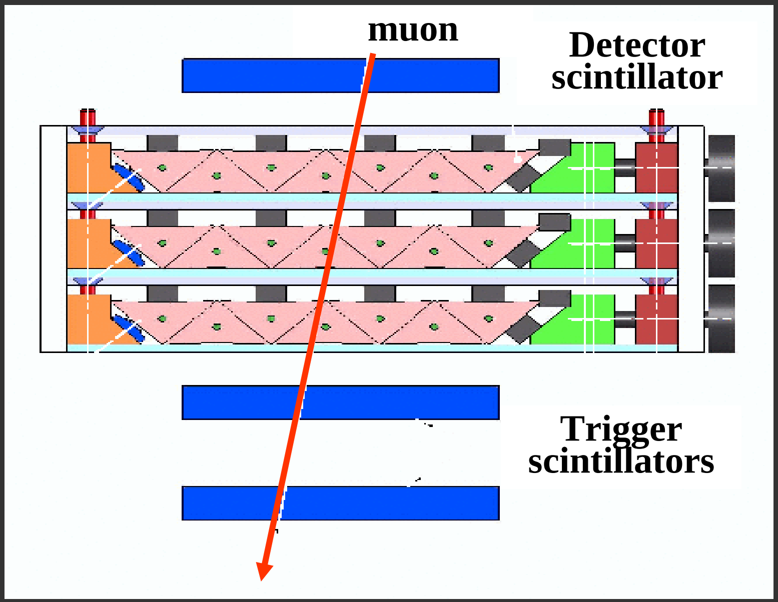


Fiber/connector light attenuation test



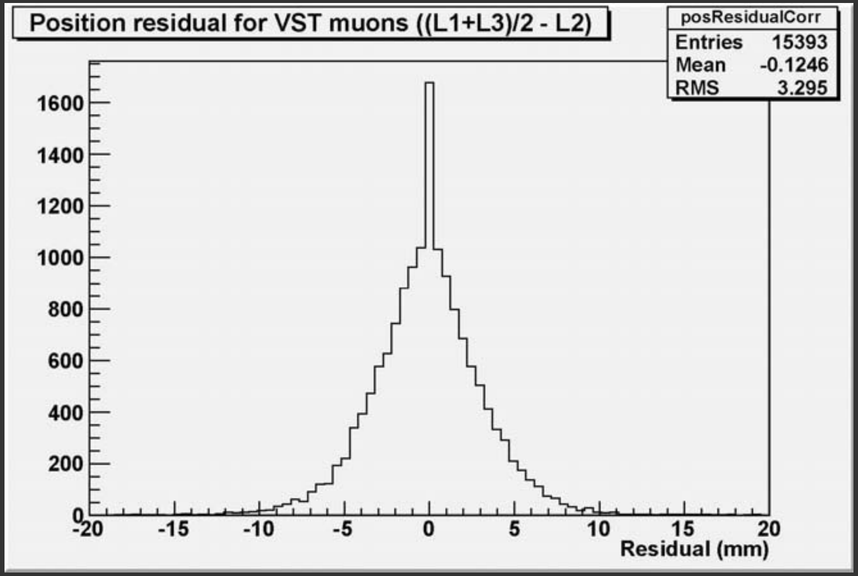
FNAL Ice polished fiber in connector

MINERνA: R&D / Prototyping / expected performance



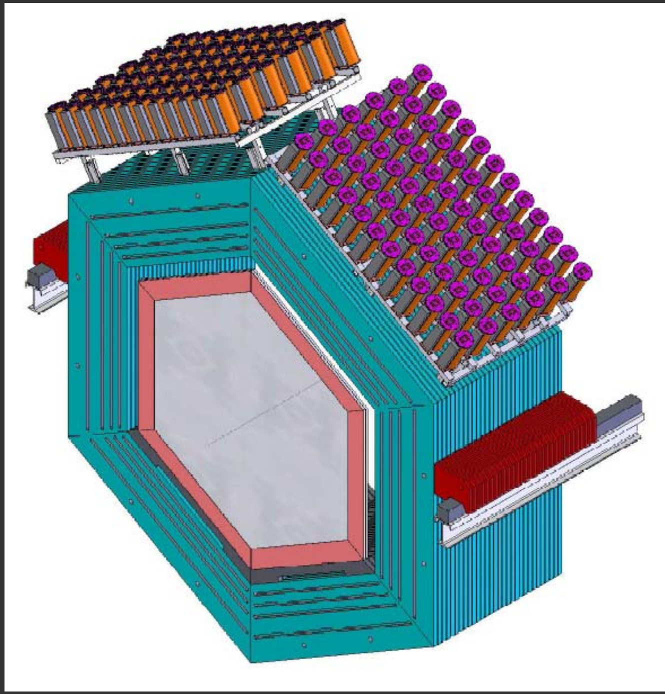
Howard Budd
Jesse Chvojka

- Vertical slice test
  - 3-layer, 21 scintillator prototype (including MINERνA electronics)
  - Measured 21 pe/MIP for each layer
  - Min-I track position resolution measured to be 3.4 mm



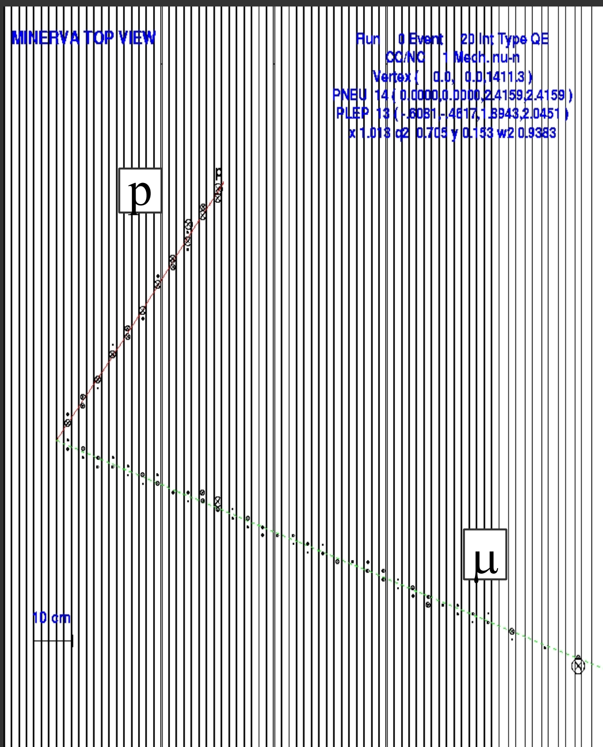
MINERνA: Cost and expected schedule

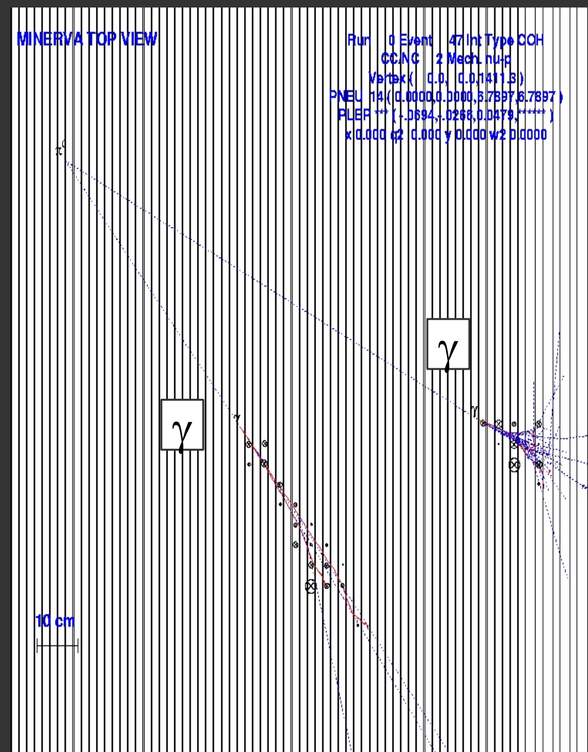
- Roughly $17M with contingency, escalation and burdened
- 2006 Continue R&D with Vertical Slice Test
- 2007 Multi-plane Tracking Prototype:
  - Roughly 20% of the full detector
  - Full EM Pb Calorimeter, no hadron Calorimeter
  - Tests to be performed
    - Construction procedures
    - Scintillator spacing uniformity
    - Plane uniformity across many planes
    - Planes stacked as close as physics dictates?
    - How to replace PMT Boxes /front end boards)

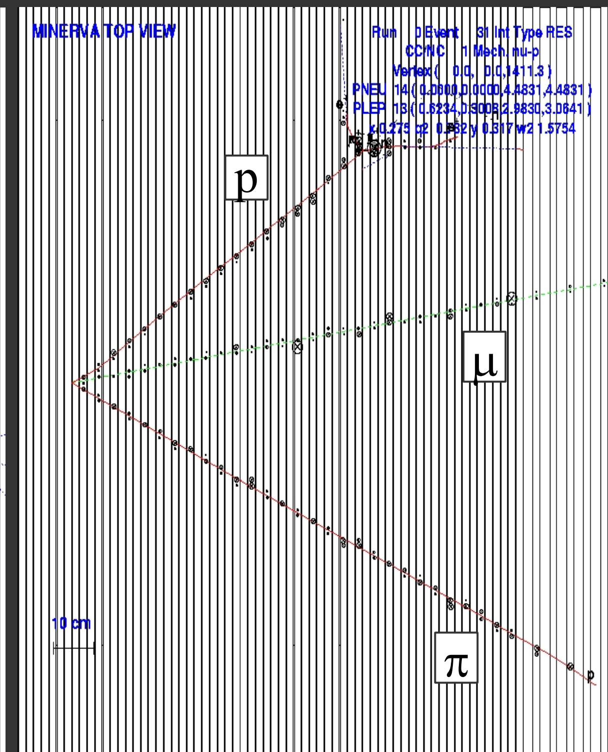


- 2008 Construction Begins
- 2009 Cosmic Ray Data and hopefully some neutrino data

MINERνA Events







Quasielastic event

$\nu_\mu\, n \rightarrow \mu^-\, p$

Neutral Current π^0

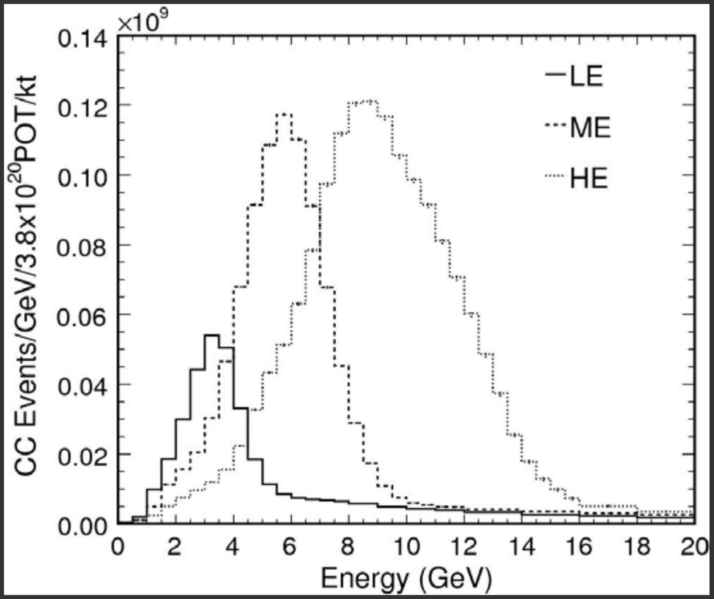
$\nu_\mu\, A \rightarrow \nu_\mu A\, \pi^0$

Resonance production

$\nu_\mu\, p \rightarrow \mu^-\, \Delta^{++} \rightarrow \mu^-\, p\, \pi^+$

MINERνA Event Rates

NUMI Beams



- **Fiducial Volume**
  - **~3 tons CH**
  - **~0.6 t C**
  - **~0.5t Fe**
  - **~0.5t Pb**
- **Expected CC event samples**
  - **8.6 M ν events in CH**
  - **0.4 M ν events in C**
  - **2.0 M ν events in Fe**
  - **2.5 M ν events in Pb**

Assumes 16.0×10^{20} in LE and ME NuMI beam configurations over 4 years

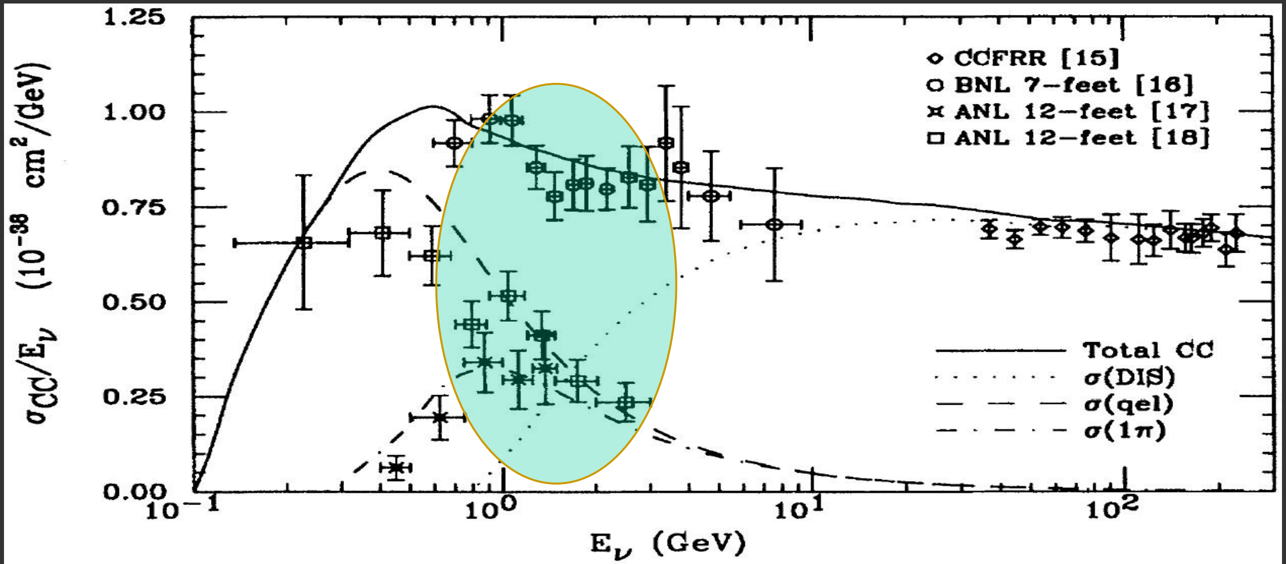
Main CC Physics Topics (Statistics in CH)

Quasi-elastic	**0.8 M events**
Resonance Production	**1.6 M total**
Transition: Resonance to DIS	**2 M events**
DIS, Structure Funcs. and high-x PDFs	**4.1 M DIS events**
Coherent Pion Production	**85 K CC / 37 K NC**
Strange and Charm Particle Production	**> 230 K fully reconstructed**

MINERνA Physics: Low Energy Neutrino Scattering

*Lipari, Lusignoli and Sartogo, PRL **74**, 4384 (1995)*

We will be making precision measurements of low energy neutrino cross sections:



Contributions to total cross section: $\sigma_{TOT} = \sigma_{QE} + \sigma_{RES} + \sigma_{DIS}$

σ_{QE}: Quasi-elastic -> $\nu(\overline{\nu})\, n(p) \rightarrow \mu^{-}(\mu^{+})\, p(n)$

σ_{RES}: Resonance -> $\nu N \rightarrow \mu N^{*}$ Inelastic, Low-multiplicity final states

σ_{DIS}: Deep Inelastic Scattering -> $\nu N \rightarrow \mu X$ Inelastic, High-multiplicity final states

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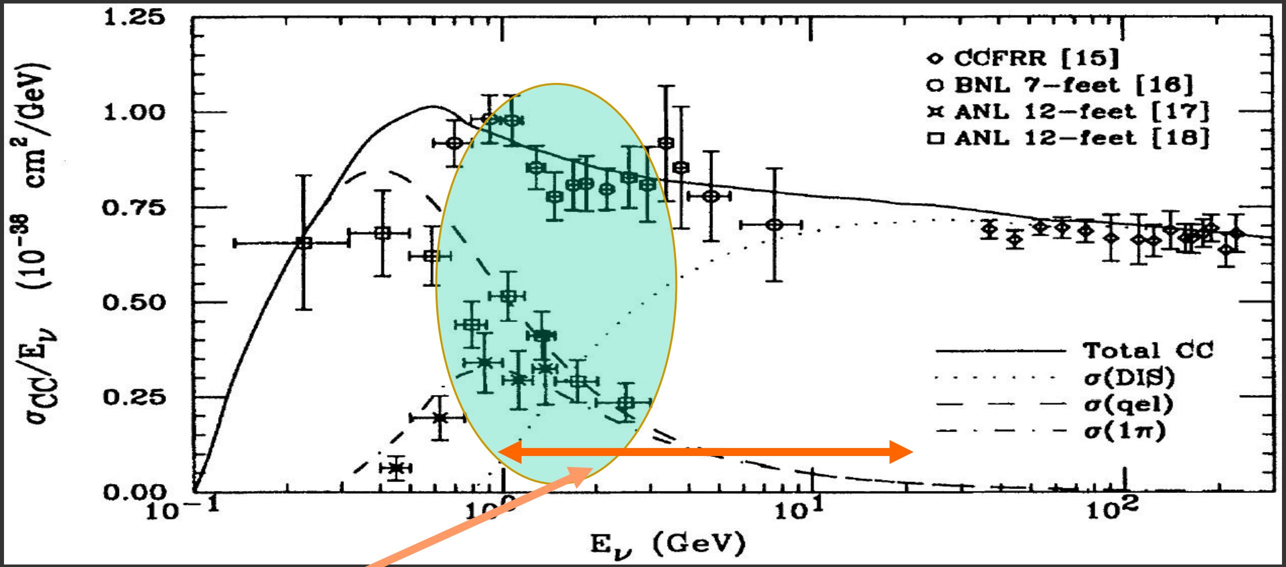
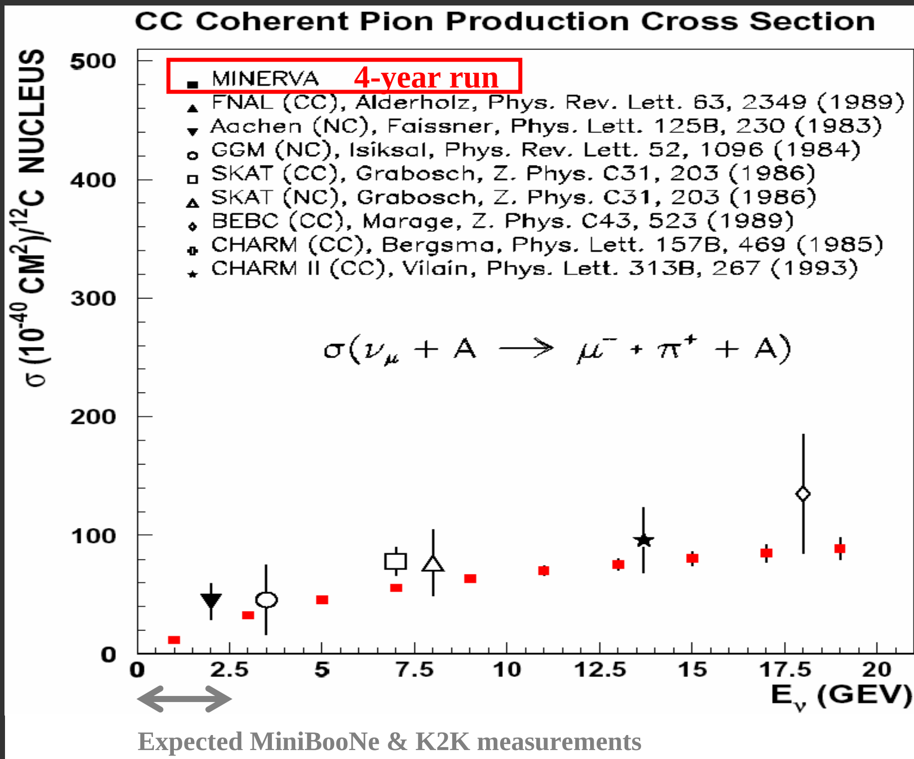


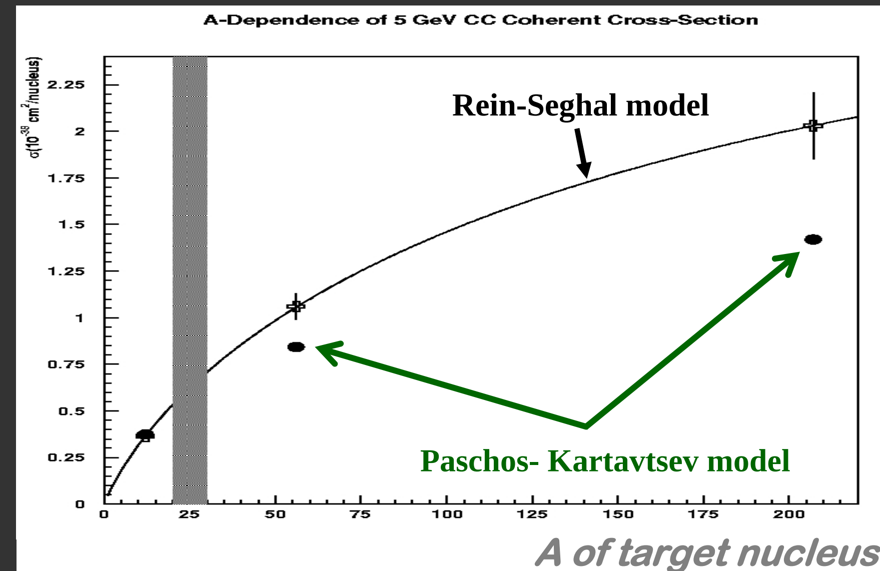
NuMI flux range 1-20 GeV

Estimated Cross section uncertainties

Process	Current	After MINERνA
QE	20%	5%
Res	40%	5/10%(CC/NC)
DIS	20%	5%
Coh	100%	20%

Coherent Pion Production





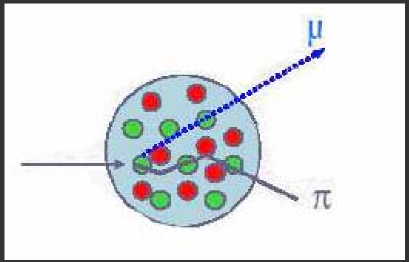
MINERνA's nuclear targets allow the first measurement of the *A*-dependence of σ_{coh} across a wide *A* range ➔ Distinguish between models

- Provides a test of the understanding of the weak interaction
  - Cross section can be calculated in various models
- Neutral pion production is a significant background for neutrino oscillations
  - π^0 shower easily confused with an electron shower: $\nu_\mu \rightarrow \nu_e n \rightarrow e^- p,\ \nu_\mu A \rightarrow \nu_\mu \pi^0 A$

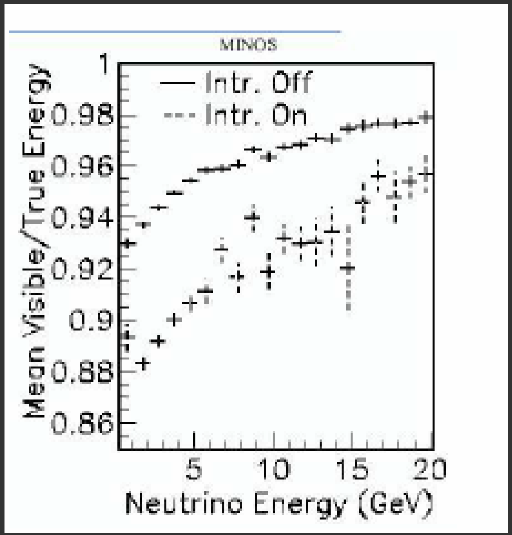
MINERνA and Oscillations
Example: Nuclear Effects on MINOS

Final State Interactions

- Intranuclear rescattering
- Energy loss and/or absorption
- Change in direction



MINOS Iron Calorimeter -
Nuclear effects among
the largest systematics



D. Harris et al. hep-ex/0410005

Changes measured visible energy
Spectrum: Translate to shift in Far/Near
'dip' location -> Δm^2

MINERνA will perform measurements with high-A targets and high-statistics

MINERνA and Oscillations
Example: Nuclear Effects on MINOS

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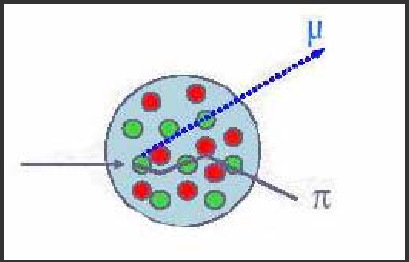
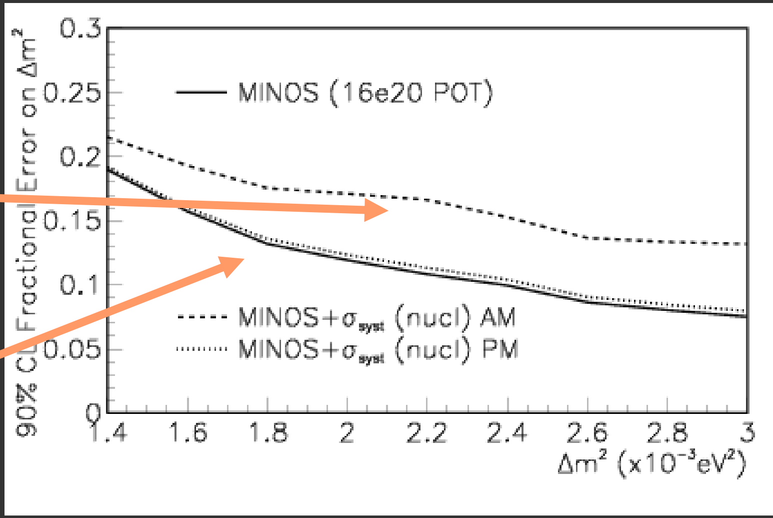


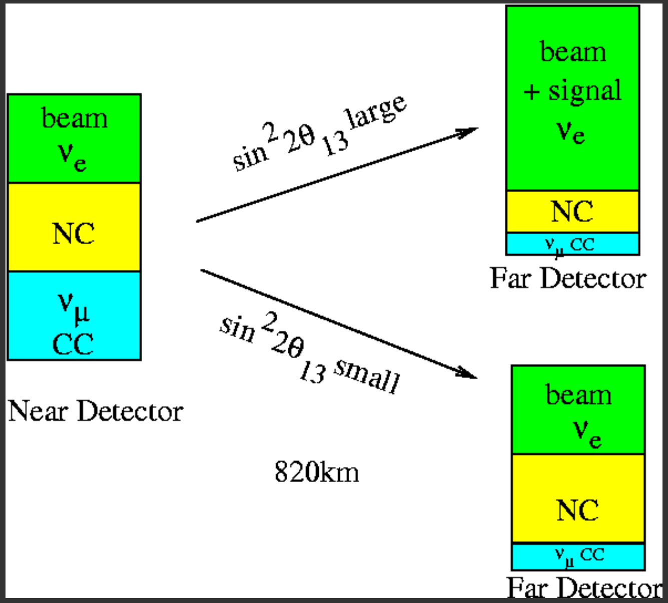
Before MINERνA
$\sigma_{stat} \sim \sigma_{syst}$ (rescattering only)

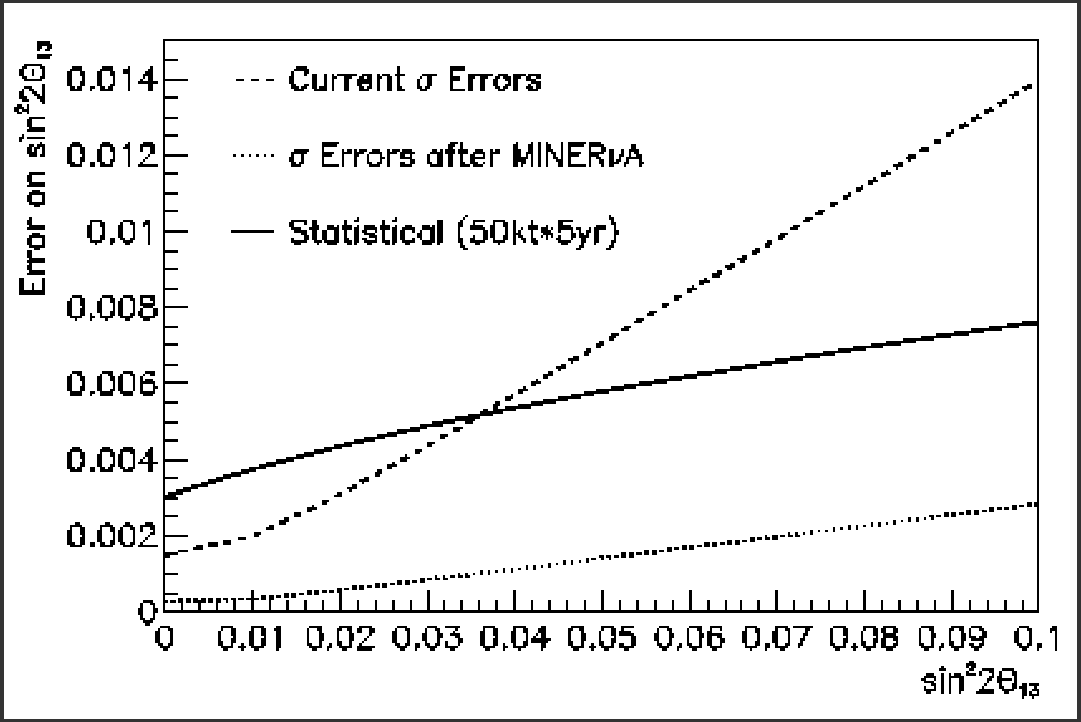
After MINERνA:
$\sigma_{stat} >> \sigma_{syst}$ (rescattering only)



MINERνA will perform measurements with high-A targets and high-statistics

How NOνA will use MINERνA Measurements

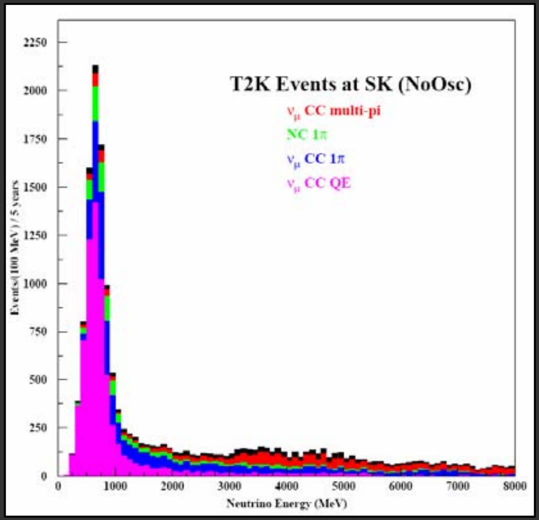


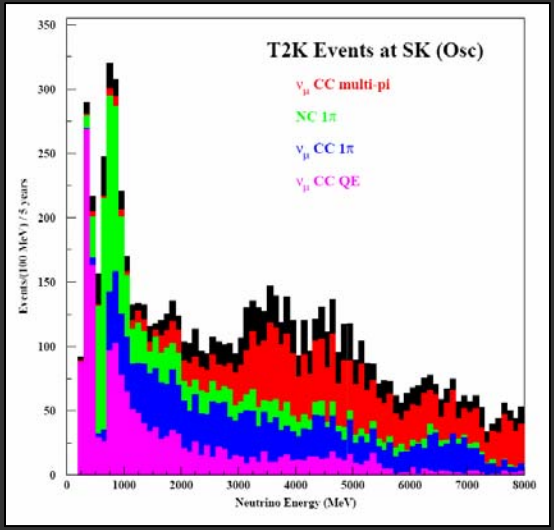


Process	QE	RES	COH	DIS
δσ/σ NOW (CC,NC)	20%	40%	100%	20%
δσ/σ after MINERνA (CC/NC)	5%/na	5%/10%	5%/20%	5%/10%

Study is for old NOνA design, but results expected to be qualitatively similar with TASD design

How will T2K use MINERvA measurements





D. Harris et al. hep-ex/0410005

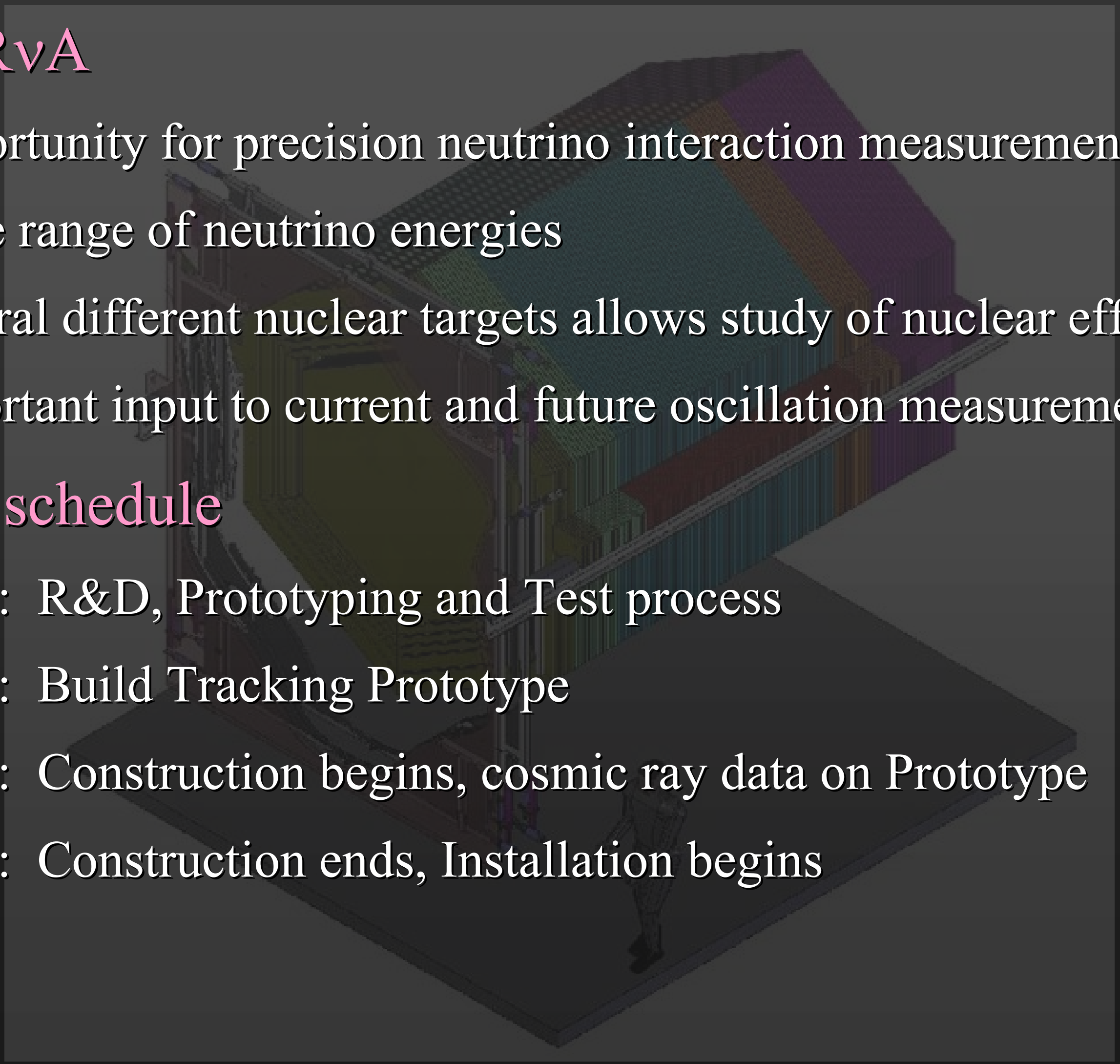
Note that as in NOvA, T2K's near detector will be a very different mix of events than the far detector.

To make accurate prediction, need

- 1 - 4 GeV neutrino cross sections
- Energy Dependence of cross sections

MINERvA can provide these with NuMI beamline Low Energy running!

Summary



- MINERνA
  - Opportunity for precision neutrino interaction measurements
  - Wide range of neutrino energies
  - Several different nuclear targets allows study of nuclear effects
  - Important input to current and future oscillation measurements
- Project schedule
  - 2006: R&D, Prototyping and Test process
  - 2007: Build Tracking Prototype
  - 2008: Construction begins, cosmic ray data on Prototype
  - 2009: Construction ends, Installation begins